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The Relative Efficiency of certain Methods of performing Artificial Respiration in Man.

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The Relative Efficiency of certain Methods of performing Artificial Respiration in Man. By E. A. Schäfer, F.R.S. (With a Plate.)

(Read December 21, 1903.)

Preliminary observations upon this subject, which were made by the author on behalf of a committee of the Royal Medical and Chirurgical Society of London, are published in a report presented by the committee and read on May 26th of this year before that Society.

The methods which were then investigated comprised traction by the arms with alternate relaxation, with and without chest compression; and pressure upon the chest walls alternating with relaxation from removal of the pressure; the subjects of the experiment being for each method placed successively in the supine, the prone and the lateral positions (in the last-named case one arm only being used for traction). In addition, the method of Marshall Hall was similarly tested. In this, the subject is alternately rolled over from the lateral to the prone position, expiration being assisted by pressure upon the back whenever the subject is brought to the prone position.

It was evident from those experiments that it is possible by nearly all the methods investigated to obtain an exchange of air per respiration as great as that of the tidal air, the sole exception being the methods in which traction alone, without alternating pressure upon the lower part of the chest, was employed.

The number of experiments which we were able to make at the time was, however, too limited to enable us to draw any positive conclusion regarding the relative value of the several methods of performing artificial respiration in man which have at various times been recommended, although the experiments clearly show the very important part which alternating pressure upon the

lower part of the chest plays in effecting the emptying and (by resiliency) the consequent filling of the lungs. It has seemed desirable, therefore, to supplement them by further experiments, having for their object the exact determination of the amount of air exchanged, not only per respiratory movement, but also per unit of time, a factor which was left out of account in the earlier experiments, but one, nevertheless, of considerable importance.

The apparatus which was used in the experiments referred to in the report consisted of a counterpoised bell-jar, filled with air and inverted over water; to or from this the air of respiration was conducted from the mouthpiece (or mask) by a curved tube which passed through the water and opened into the bell-jar. When, therefore, air was drawn by the movement of inspiration from the bell-jar this sank in the water, and when air was forced into it by the movement of expiration it rose. These movements of the bell-jar were recorded upon a slowly moving blackened cylinder, and the diameter and corresponding cubic contents of the bell-jar being known, the amount of air exchange was found by measuring the ordinates of the curves described on the cylinder. The readings, however, must be looked upon as only approximate, because, firstly, the bell-jar which was used was only approximately cylindrical; and secondly, because the counterpoised bell-jar acquired, with the somewhat rapid movements imparted to it, a swing of its own which must have affected the record.

In order to obtain more accurate measure of the amount of air exchanged in respiration, the apparatus which was employed in these earlier experiments has been discarded, and we have used a carefully constructed graduated gasometer (spirometer), counterpoised on the principle devised by the late Dr W. Marcet to avoid the error which arises from the fact that the more a gasometer is raised out of the water in which it is inverted, the greater is the pressure exerted upon its contents. The air which is pumped out of the chest is alone measured, but it is clear that an equal amount must afterwards pass in to take its place. The air is respired through either a mask or mouthpiece. In practice the latter is found to be the more convenient, as less liable to accidental leakage. When it is used, the nostrils must be occluded

by pinching the nose either by the fingers or by a spring clip. The tube which leads from the mouthpiece is forked, and each fork passes to a water valve, one for admitting air to the mouthpiece, and the other to enable the air which is driven out of the chest to pass through on its way to the gasometer. The air which is pumped into the gasometer can either be read off at once on a scale attached to the instrument, which is graduated in litres and tenths of a litre, or it can be graphically recorded by attaching a pen to the moving (ascending) gasometer, allowing this both to

Fig. 3.—Silvester method.

register the extent of each movement and also the number of respiratory movements per minute upon a blackened drum revolving slowly by means of clockwork, and upon which a time tracing is also recorded. The tracings so obtained can be afterwards studied at leisure.

Fig. 1 is a photograph showing the arrangement of the apparatus.

Fig. 2 shows the manner in which any respiratory method is investigated by it. The method shown in the photograph is that of intermittent pressure upon the lower ribs, with the subject in the prone position.

Figs. 3, 4 and 5 are samples of tracings obtained by this method. The 'steps' upon each curve mark the successive

respiratory movements; each 'rise' gives the amount of air expired; inspiration occurs during the 'tread' of each step; the intervals between the horizontal lines represent 500 c.c.; the time tracing shows a mark every ten seconds.

The tracings reproduced in figs. 3, 4 and 5 were all taken at the same time and from the same individual. The experiment begins in each case at the bottom, and is continued until the pen has nearly reached the top of the paper. The drum was then stopped and the cylinder (and pen) lowered (continuous vertical

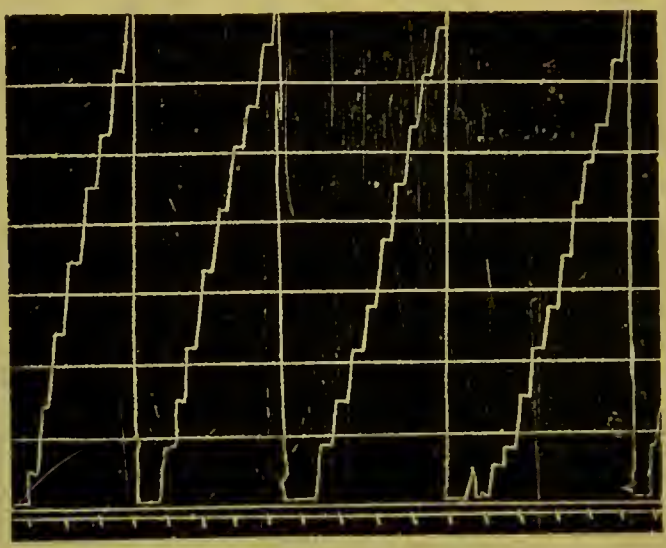

FIG. 4.—Supine pressure method.

line), and after a brief interval of natural respiration another record of the particular mode of artificial respiration which was being investigated was taken. Fig. 3 illustrates the amounts of air exchanged in the employment of the Silvester method* (forcible raising and subsequently lowering the arms, followed by lateral pressure upon the chest); fig. 4, the amount exchanged when the Howard method† was used; and fig. 5, the amount exchanged by intermittent pressure over the lower ribs, with the subject

* H. R. Silvester, *The Discovery of the Physiological Method of inducing Respiration in Cases of apparent Death from Drowning, Chloroform, Still-birth, Noxious Gases, etc. etc.*, 3rd edition, London, 1863.

† B. Howard, *Plain Rules for the Restoration of Persons apparently Dead from Drowning*, New York, 1869.

in the prone position. The amount of pressure used in the last two methods was approximately the same, having been produced by throwing the whole weight of the fore part of the body of the operator upon his hands, which were placed over the lowest part of the thorax of the subject, the only difference being that in the one case (Howard) the subject was supine, in the other prone. The pressure was in every case applied and removed gradually; a pressure of about 60 lbs. was thereby exerted.

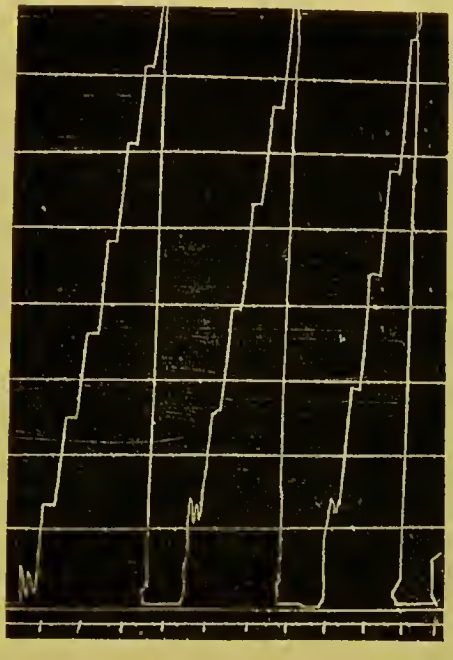

Fig. 5.—Prone pressure method.

Fig. 6 shows two tracings obtained by permitting the subject to breathe, under approximately natural conditions, into the spirometer, and the steps on these tracings give, therefore, an idea of the amount of tidal air. The rate of respiration on this occasion was about 16 per minute, and the average amount of air exchanged at each respiration (*i.e.* the amount of tidal air) was 385 c.c., or 6160 c.c. per minute. Before and after these two tracings, others were made with employment of the prone-pressure method; and these, which are also shown in the figure, illustrate well the efficiency of that method in providing a due exchange of air.

The following tables will serve to show the results yielded by the four principal methods which have been recommended for artificial respiration in man. In each case the respirations were performed during five minutes, but as the spirometer was only graduated to ten litres, it was necessary to take the amount of air yielded by each minute separately. In the intervals the subject was allowed to breathe naturally. There are also two tables (I. and II.) giving the amount of air breathed naturally into the spirometer, the circumstances being otherwise similar.

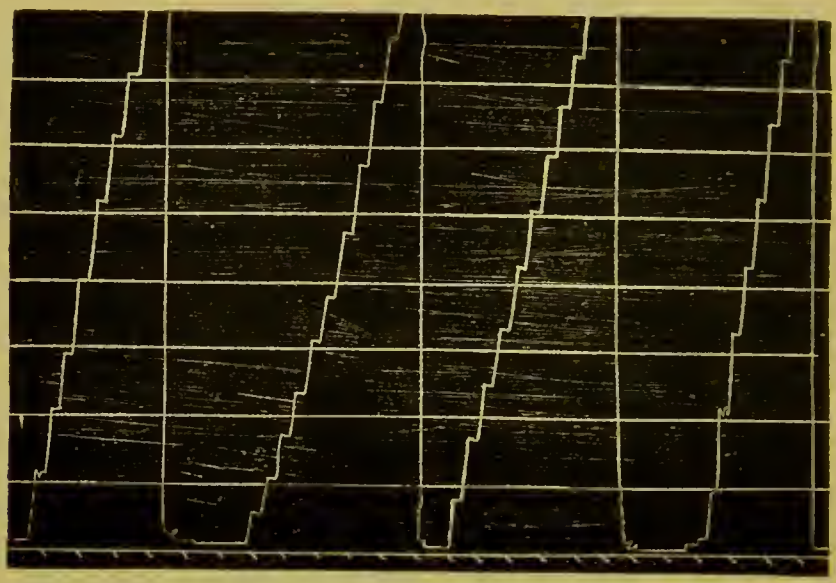

FIG. 6.—Two middle tracings, natural respiration; two lateral tracings, artificial respiration by prone pressure method.

In the one series of these the subject was supine, in the other prone. Since, from the result recorded in these two tables, it appeared that the normal rate of respiration was about 13 per minute in the subject under the conditions of the experiment, this was the rate aimed at in performing artificial respiration. The same operator and the same subject took part in all the experiments. The amount of pressure produced by the weight of the upper part of the body of the operator when thrown forward on to his hands in performing the artificial respirations, shown in Tables IV. and VI., was determined to be about 60 lbs. The statistics of the subject of experiment are as follows:—

Male; age, 23; occupation, laboratory attendant; height, 5 feet 7¼ inches (1·71 m.); chest measurement (at mammary line and in full inspiration), 38½ inches (0·978 m.); weight, 10 stone 1½ lbs. (64 kilog.); vital capacity, 4450 c.c.

TABLE I.—*Tidal Air of Natural Respiration—supine position.*

	Number of Respirations.	Amount of Air in Cubic Cent.
1st minute,	14	6,700
2nd ,,	13	6,200
3rd ,,	14	6,500
4th ,,	13	6,600
5th ,,	12	6,300
In 5 minutes,	66 respirations.	32,300 c.c. air respired.

Remarks.—The average number of respirations per minute was 13. The average amount of air exchanged per respiration was 489 c.c., and per minute 6460 c.c.

TABLE II.—*Tidal Air of Natural Respiration—prone position.*

	Number of Respirations.	Amount of Air in Cubic Cent.
1st minute,	12	5,300
2nd ,,	12	6,000
3rd ,,	12	5,000
4th ,,	13	4,200
5th ,,	13	5,700
In 5 minutes,	62 respirations.	26,200 c.c. air respired.

Remarks.—This gives about 12½ respirations per minute, with an air exchange per respiration of 422 c.c., and per minute of 5240 c.c.

Combining the results given in Tables I. and II., the tidal air of the individual under experiment averages 456 c.c.

TABLE III.—*Silvester Method.* (Forcible traction upon the arms, followed by bringing of the arms back to the side of the chest and pressure upon the chest.)

	Number of Respirations.	Amount of Air in Cubic Cent.
1st minute, ...	13	3,700*
2nd ,, ...	12	2,100
3rd ,, ...	13	1,600
4th ,, ...	13	1,700
5th ,, ...	13	2,300
In 5 minutes, ...	64 respirations.	11,400 c.c. air exchanged.

Remarks.—The average number of respirations per minute was 12·8, and the amount of air exchanged per respiration averaged 178 c.c., and per minute 2280 c.c.

The amount of physical exertion required to effect even this amount of air exchange was very great, and it would have been impossible to continue it for any length of time. Moreover, the subject could scarcely sustain the effort not to breathe, for the amount of air he was receiving was quite inadequate, his natural tidal air being about 450 c.c. per respiration, and 5850 c.c. per minute (see Tables I. and II.). The subject was on the ground, with a folded coat under the shoulders; the operator at his head, in a semi-kneeling posture.

TABLE IV.—*Supine Pressure (Howard's) Method.* (Intermittent pressure over the lower ribs, with the subject in the supine position.

	Number of Respirations.	Amount of Air in Cubic Cent.
1st minute, ...	14	4,000
2nd ,, ...	14	4,100
3rd ,, ...	14	3,900
4th ,, ...	13	3,500
5th ,, ...	13	4,600
In 5 minutes, ...	64 respirations.	20,100 c.c. air exchanged.

* The relatively large amount recorded here was probably due to the lungs having been unusually well filled by the subject just before the experiment commenced.

Remarks.—The average number of respirations was 13·6 per minute, and the amount of air exchanged works out at 295 c.c. per respiration, and 4020 c.c. per minute. Very little physical exertion is required with this method, especially with the patient on the floor, since it merely consists in throwing the weight of the operator's body forward upon his hands and alternately swinging back to relieve the pressure. The amount exchanged in this experiment, although far more than by the Silvester method, was not up to the tidal air standard, but the deficit was not sufficient to cause any feeling of distress to the subject of the experiment during the minute that each bout of respirations lasted.

Table V.—*Marshall Hall Method.** (The patient is laid prone and rolled over to one side and back again, and so alternately. When in the prone position, pressure was during three of the five-minute intervals exercised upon the back of the chest.)

	Number of Respirations.	Amount of Air in Cubic Cent.
1st minute (with pressure), . .	13	3,100
2nd ,, (with pressure), . .	14	3,500
3rd ,, (without pressure ; rolling only), ...	12	2,400
4th minute (without pressure ; rolling only), ...	12	2,200
5th minute (with pressure), . .	12	3,300
In 5 minutes, ...	63 respirations.	14,500 c.c. air exchanged.

Remarks.—The average number of respirations was 12·6 per minute, and the amount of air exchanged per respiration comes to 230 c.c. If the three minutes during which pressure was alternated with the rolling over are alone taken into consideration, the exchange with each respiration works out at 254 c.c. The rolling without pressure gave 192 c.c. per respiration. Since the method as recommended by Marshall Hall embraces alternating

* Marshall Hall, *Prone and Postural Respiration in Drowning, etc.*, London, 1857.

pressure upon the back, the highest of these three numbers may be adopted, viz., 254 c.c. per respiration (3300 c.c. per minute). This amount, as compared with the tidal air of 450 c.c. per respiration, and 5850 c.c. per minute, is obviously inadequate; and, conformably with this, the subject experienced distinct distress towards the end of each minute, even when pressure was used. In the experiments without pressure, the minutes had to be cut up on this account into two periods of half a minute each.

Although not a great deal of physical exertion is required to roll a body half over in this way some 12 or 13 times a minute and alternately to press upon the back, yet the labour is much greater than that required by the simple pressure method. Such efficiency as the method may have depends largely upon the alternating pressure, for without this the rolling is quite ineffective. The reason why this pressure produces less effect than in the method next to be considered appears due to the fact that the time taken up by the rolling enables less time to be given to the pressure, so that this is almost necessarily inadequately performed if the normal rate of respiration is kept up.

TABLE VI.—*Prone Pressure Method.**—(This is similar to the Howard method (intermittent pressure on the lower ribs), but the subject is in the prone position.)

	Number of Respirations.	Amount of Air in Cubic Cent.
1st minute, ...	12	6,100
2nd ,, ...	13	6,800
3rd ,, ...	14	6,750
4th ,, ...	12	7,000
5th ,, ...	14	7,200
5 minutes, ...	65 respirations.	33,850

Remarks.—The rate of respiration was on the average 13, and the amount of air exchanged averaged 520 c.c. per respiration,

* This method is described in a paper communicated by the author to the Royal Medical and Chirurgical Society, which was read on December 8th, 1903, and will be published in the *Med. Chir. Trans.*

and 6760 c.c. per minute. It is the only method which, in this series of experiments, gave an amount equal to the normal tidal air of the individual—which was, in fact, somewhat exceeded. Not that it is impossible by other methods (especially those of Howard and Marshall Hall) to obtain larger figures for the exchange air than those given in the tables here shown—figures equal to or even larger than the tidal air—but merely because it is more difficult to do so at the rate of artificial respiration at which these experiments were carried on. The most important fact which the tables show is that at this rate (which is the normal rate of this particular individual, and not by any means a fast rate), it is easily possible to pump far more air into and out of the chest by the prone-pressure method than by any of the methods generally employed. The actual pressure exerted upon the prone subject was not greater, probably rather less, than upon the supine subject, in which the *full* weight of the fore part of the operator's body was certainly thrown upon the lower ribs, whereas in the similar experiments upon the prone subject the outflow of air on making pressure on these ribs was so abundant and easy that there was a tendency for the operator not to throw the whole weight on the hands; even more air, therefore, could have been exchanged if desired.

TABLE VII.—*The following Table gives the main results of all the foregoing Tables in a summarised form.*

Mode of Respiration.	Number per Minute.	Amount of Air exchanged per Respiration.	Amount of Air exchanged per Minute.
Natural (supine), . .	13	489 c.c.	6,460 c.c.
Natural (prone), . .	12·5	422 ,,	5,240 ,,
Prone pressure, . .	13	520 ,,	6,760 ,,
Supine pressure, . .	13·6	29[illegible] ,,	4,020 ,,
Rolling (with pressure), .	13	254 ,,	3,300 ,,
Rolling (without pressure),	12	192 ,,	2,300 ,,
Traction (with pressure), .	12·8	178 ,,	2,280 ,,

Results similar in character to the above have been yielded by many experiments, both upon the same and upon different individuals. These experiments all show that by far the most efficient method

of performing artificial respiration is that of *intermittent pressure upon the lower ribs with the subject in the prone position.* It is also the easiest to perform, requiring practically no exertion, as the weight of the operator's body produces the effect, and the swinging forwards and backwards some thirteen times a minute, which is alone required, is by no means fatiguing.* This statement also applies to the supine-pressure method when effected slowly and without undue violence. But not only is this method less efficient than the prone-pressure method, but there are undoubted dangers attending it, especially in those cases where the asphyxial condition is due to drowning. For in drowned individuals the liver is enormously swollen and congested, and ruptures easily, as Dr Herring and I found when endeavouring to resuscitate drowned dogs by this method of artificial respiration.† And further, the supine position is contra-indicated both in drowning and in asphyxia generally, since it involves the risk of obstruction of the pharynx by the falling back of the tongue, and also fails to facilitate the escape of water, mucus, and vomited matter from the mouth and nostrils.

The Silvester method, as compared with the others, has nothing in its favour. It has all the disadvantages of the supine position, is most laborious, and is relatively inefficient. As regards the Marshall Hall method, the most effectual part of that method is the exertion of pressure in the prone position; the rolling over is quite unnecessary, and attended by manifest disadvantages. The addition to this method which is advocated by Bowles,‡ consisting in raising the one arm over the head after the body is placed in the lateral position, has been found, in measurements we have made, to introduce no serious augmentation in the amount of air exchanged, but merely serves to render it still more difficult to perform the respiratory movements efficiently at the necessary rate.

* I have on one occasion continued it for nearly an hour without experiencing the least fatigue, and without the subject having any desire to breathe naturally or feeling at all inconvenienced.

† Report of Committee of Royal Medical and Chirurgical Society, *op. cit.*

‡ R. L. Bowles, *A Method for the Treatment of the apparently Drowned*, London, 1903.

(*Issued separately January* 29, 1904.)

Fig. 1.

Fig. 2.

Prof. E. A. Schäfer.